LTCC Short Range Radar Sensor for Automotive Applications at 24 GHz

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Abstract: This paper presents the concept, design and measurement results of an FMCW radar module with an integrated planar antenna array, realised in LTCC (Low Temperature Cofired Ceramics) technology, for automotive applications operating at 24 GHz. A car manufacturer has specified the requirements for antenna and microwave module. The resulting design concept is discussed and subsequently, simulation and measurement results are presented to verify the feasibility of the concept. The high degree of integration enabled by LTCC leads to a very compact sensor module. Considerate material selection and hybrid integration of discrete semiconductor devices lead to very competitive production costs. The well-established screen-printing process used in LTCC is a further benefit in the mass production of this rugged design.

Keywords: LTCC, 24 GHz, Radar Sensor, FMCW, Planar Antenna, Automotive

Introduction

The RADAR-sensor presented here is designed for use as driver assistance system in vehicles. FMCW method is utilized to measure distances up to 30 m and velocity of obstacles around the car. Especially safety enhancement systems like collision warning and mitigation but also comfort features can be realized. Moreover, the sensor is capable to be integrated in manifold industrial applications where distance and velocity have to be determined with high precision. Another interesting field of application is the monitoring of buildings and real estates, because the module concept is qualified for the free 24 GHz ISM band, too.

For the production of highly integrated modules, LTCC is appreciated for its flexibility in realising an arbitrary number of layers with easy-to-integrate circuit components like thick film resistors, cavity-buried or top-mounted SMT components, or even chip devices.

Basic Principle of Operation

Unlike most of the other electronic solutions for radar sensors available to today’s car industry, which are based on pulse methods, the sensor featured in this paper is based on the FMCW principle of operation. The carrier signal of the radar is frequency modulated in linear ramps. The sensor receives and transmits simultaneously, and the frequency difference \( \Delta f \) between the transmitted and received signal (e.g. between two objects) is proportional to the time difference of the two signals. The time difference of the two signals is in turn proportional to the distance between the transmitter and the reflecting object, thus determining very accurately, through the frequency difference \( \Delta f \), the distance between the two objects.

Specification of the RADAR module:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>FMCW</td>
</tr>
<tr>
<td>Centre Frequency</td>
<td>24 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Resolution</td>
<td>± 10 mm</td>
</tr>
<tr>
<td>Obstacle Separation</td>
<td>± 100 mm</td>
</tr>
<tr>
<td>Distance</td>
<td>10 cm to 30 m</td>
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<tr>
<td>Output Power</td>
<td>&lt; 10 dBm</td>
</tr>
</tbody>
</table>

RF-Module

The main focus of the development is directed towards the reduction of costs in comparison with conventional sensors. Hybrid circuit technology using a 5-layer LTCC substrate from DuPont Microcircuit Materials has been realized. The module is assembled with cost-effective discrete semiconductor devices, avoiding the use of expensive monolithic integrated circuits (MMICs). The patch-antenna is printed on one side of the multilayer ceramic, while the RF front-end has been integrated on the opposite side. The microwave front-end with the integrated patch antenna measures only 34 mm x 21 mm.
Signal conversion and signal processing are executed on an external board, which is connected via USB interface to a PC. All results are evaluated and presented on the computer. Software with graphical user interface allows the setting of sensor and evaluation parameters.

![Block Diagram](image1)

**Fig. 1:** Block Diagram

The Voltage Controlled Oscillator (VCO) provides the frequency modulated transmit signal. A single stage class A buffer amplifier isolates the VCO and delivers the appropriate transmit power level. The branch-line 90° hybrid coupler is used to direct the incident wave to the antenna and the mixer and the reflected wave from the antenna to the mixer. The single balanced mixer consists of a rat-race coupler and a matched pair of diodes. For further processing the IF-output of the module is amplified.

![Component Side of the Sensor](image2)

**Fig. 2:** Component Side of the Sensor

**Antenna**

Considering wireless or radar applications, the idea of integrating the antenna within the module is quite appealing: the integration of the antenna makes the antenna connector obsolete and minimizes the feeding line length, thus reducing feeding losses. Yet, due to the high dielectric constant of the LTCC material, the design of a broadband planar antenna array is quite challenging: the bandwidth decreases with the dielectric constant. However, LTCC materials are ideally suited for multilayer structures; this characteristic can be exploited by using stacked patch elements, thus considerably enhancing the bandwidth [4]. The antenna design presented here is based on this principle.

**Antenna Requirements**

The antenna has to comply with the following specifications: The operation frequency range is defined by a centre frequency of 24 GHz, with a bandwidth of at least 2 GHz. This broadband behaviour is important, since the range of the frequency modulation ramp of the radar module defines its resolution. The polarisation of the antenna has to be linear, with a high suppression of the cross polar components. The antenna pattern should meet the 3dB beam width requirement of ±15° in the E-plane and ±30° in the H-plane. Of course, other automotive radar applications might require a different antenna pattern. It is therefore important to point out that the concept presented here could easily adopted to other requirements by changing the number of elements in the array, while maintaining the basic antenna architecture, and thus the broadband characteristic of the antenna.
The antenna module consists of five LTCC layers, each with a 200 µm layer thickness. Fig. 1 depicts the layout of the complete FMCW radar module. Fig. 4 shows this module in a cross sectional view. The bottom side of the ceramic block carries the RF front-end circuits and components. An aperture in the buried ground plane between the first and second ceramic layer (counted from the bottom), is used to interconnect RF and antenna circuitry. The antenna array and its feeding lines are located between the third and fourth layer. Stacked patches on the topside of the ceramic are used to enhance the bandwidth of the antenna [2]. The ceramic material consists of DuPont 951-AT green tape, with a dielectric constant of 7.8, and a loss tangent of 0.008 [1]. This material has been favoured for reasons of economy, since it is cheaper than the similar low loss material, DuPont 943-A5, with an indicated loss tangent of 0.001 [1].

The complete antenna has been calculated including the RF-to-antenna interface using the FDTD simulator EMPIRE™[3]. The simulation results in Fig. 5 show the calculated return loss of the antenna. The 10 dB bandwidth of the antenna is about 2.5 GHz, giving a relative bandwidth of over 10%. Considering the high dielectric constant of the material used, this is a remarkably good result. The simulation results of the far field behaviour are depicted in Fig. 6 and Fig. 7. The directivity of the antenna is calculated to be 12 dBi, with a 3 dB beam width of ±15° in E-plane, and ±30° in H-plane, respectively.

Fig. 5 shows the measured 10 dB bandwidth of the antenna. The deviations between simulation and measurement results can be explained by the fact that the calibration of the measurement system did not include the influence of the SMP plug nor the SMP-to-K interface. Despite these differences, the measurements clearly verify the wideband characteristic of the antenna.

Fig. 6 and Fig. 7 show the measured far field patterns of the antenna at 24 GHz in comparison with the simulation results. It can be stated that there is a good agreement between the calculated and measured radiation patterns. Moreover, the suppression of the cross-polar level is about 20 dB, meaning a good polarisation purity of the antenna. The difference between the calculated directivity and the measured antenna gain of about 10 dBi can be ascribed to losses in the material as well as in the feeding line and the connectors. This means that the actual gain of the integrated antenna will be slightly higher, since the connectors are only used for measurement purposes, and the length of the microstrip feeding line on the RF side will be reduced.
Fig. 5: Calculated and measured antenna return loss including RF-interface.

Fig. 6: Calculated directivity and measured antenna gain (H-plane).

Fig. 7: Calculated directivity and measured antenna gain (E-plane).
Conclusions
The high density of interconnects in LTCC substrates facilitates the integration of patch antenna, microwave front-end, IF electronic and optional digital part on one single multilayer LTCC substrate. Utilization of multilayer ceramic for microwave circuits allows the use of bare semi-conductor dies and the abandonment of microwave monolithic integrated circuits (MMIC), which lowers the costs, increases the availability of components and expands second source capabilities. Inherent housing properties like hermeticity, thermal conductivity and good CTE-match to semiconductors make LTCC an ideal candidate for compact and environmentally rugged modules. Despite the high dielectric constant of the LTCC material, the presented antenna concept exhibits broadband behaviour by exploiting the LTCC multilayer characteristics. The presented simulation and measurement results verify this appealing concept, which is flexible enough to be easily adapted to other radar application requirements. These advantages result in a compact Radar module, which summarizes outstanding properties like small dimensions, proper performance as well as low costs.

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References